Multiple Parton Scattering in Nuclei: Parton Energy Loss [*]

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Working in the framework of generalized factorization of higher-twist parton distributions, we have studied multiple parton scattering in deeply inelastic eA collisions, in particular the induced gluon radiation and the resultant modification to the final hadron spectra. We have defined modified quark fragmentation functions to take into account the effect of multiple parton scattering. We have presented a detailed derivation of the modified quark fragmentation functions and their QCD evolution equations to the next-leading-twist. The modification is shown to depend on twist-four parton matrix elements, both diagonal and off-diagonal, in nuclei.

Depending on whether the gluon radiation is induced by the secondary scattering, one can categorize the multiple parton scattering as soft or hard, according to the fractional momentum carried by the secondary parton involved. We have considered both soft and hard scattering and their interferences. We have shown that these are exactly the so-called LPM interference effect. We have demonstrated that LPM interferences modify the available phase space in the emitted gluon's momentum. Coupled with the gluon spectrum in QCD, this leads to the quadratical dependence of the modification of fragmentation functions or the effective parton energy loss on the nuclear size R_A.

The LPM interference effect in this study is critical for applying the LQS generalized factorization to the fragmentation processes. Because of the LPM interference effect, the gluon radiation with small transverse momentum is suppressed. Equivalently, the formation time of the gluon radiation has to be smaller than the nuclear size R_A. This requires that the radiated gluon have a minimum transverse momentum $\ell_T^2 \sim Q^2/A^{1/3}$. For such a value of transverse momentum, we can still take the leading logarithmic approximation $\ell_T^2 \ll Q^2$ in the study of fragmentation function in a large nucleus ($A \gg 1$). Therefore, the applicability of the our study here is limited to experimental situations in which Q^2 must be large enough such that $Q^2 \gg Q^2/A^{1/3} \gg \Lambda_{\mathrm{QCD}}^2$. In the meantime, the resultant nuclear corrections proportional to $\alpha_s A^{1/3}/\ell_T^2 \sim \alpha_s A^{2/3}/Q^2$ from double parton scattering are still leading for large values of Q^2. This is why the nuclear corrections to the fragmentation function and the induced parton energy loss depend quadratically on the nuclear size R_A. In the processes with large final transverse momentum $\ell_T^2 \sim Q^2$ as studied by LQS, the leading correction is instead proportional to $\alpha_s A^{1/3}/Q^2$. This is because one can neglect the interference contribution if $\ell_T^2 \gg Q^2/A^{1/3}$.

We have also considered double-quark scattering processes. Though their contributions to the QCD evolution equations can be neglected as compared to quark-gluon scattering, they do have a leading-order contribution which mixes quark and gluon fragmentation functions. Since they involve quark-antiquark correlations in nuclei, the modification to quark and antiquark fragmentation functions will be different. This might give different modification to the spectra for negative and positive hadrons as observed in experiments.

There is currently little information on the twist-four parton matrix elements in nuclei, especially the off-diagonal ones. We have only outlined a very crude estimate, assuming factorization of the two parton correlations in nuclei. This enables us to estimate the nuclear dependence of the final results. Future work on this is necessary in order to have any quantitative study of the problem. With that information, one should be able to numerically solve the QCD evolution equation for the modified fragmentation functions.